a ready graphic solution of the mysteries of frequency. Figures 2–5 illustrate such plotting.

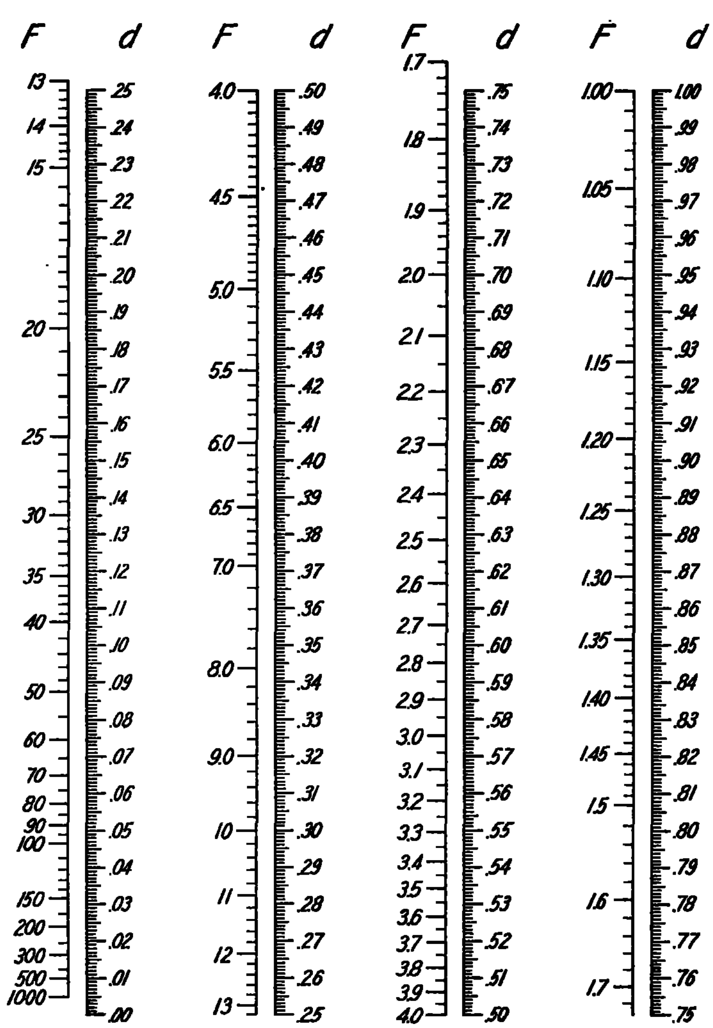
Historical and legendary information as to flows that have equalled or exceeded the maximum of record may be also utilized to extend the charted record or to correct the frequency value for the maximum discharge for short records, and the probabilities may be thereby visualized in a way that enables the mind to grasp some relations that otherwise remain obscure.

Records and historical evidence examined indicate:

1. That for large watersheds, over 20,000 to 30,000 square miles, the factor *ce* is practically constant for all frequencies.
2. That for watersheds 5,000 to 15,000 square miles, *ce* is constant for flows between limits of about 5 years out of 6 up to occurrances once in 5 to 10 years, and for more infrequent events *ce* increases with *F*.
3. That for watersheds 1,000 square miles or less, *ce* is constant from 5 years out of 6 to 1 year in 14 to 16, and for more infrequent flows *ce* increases with *F*.
4. That the variable affecting *ce* probably affects *e* only and has an inverse relation to mean annual precipitation and area, a direct relation to the tributary slope, and a relation to frequency of a similar form to that given for *Q* above.
5. That *c* has a direct relation to mean annual precipitation, and area.
6. That *e* has a direct relation to precipitation, area, and slope, and an inverse relation to storage.

Indications are that with broad enough data, the relations affecting *c* can be determined within 5 per cent of accuracy, *e* within 10 per cent, and the variable within somewhat wider limits, and this is written to assist the author in his quest for such data, long-time records being most desired.

Note added November 17, 1924.—Later investigations suggest considerable alterations in the ratios entering into the expression for *d*, and it is believed that with proper modifications those events of a frequency of once in 15 years, or of more remote occurrence, may be closely approximated as well as the more frequent events. Such a modified expression will be proposed by the author at some future date.



Values in Formula for Deduction Factor

$$d=\left(\frac{1}{2F}+\frac{4.5}{F+8}\right)$$

FIG. 1

COMPARISON OF RAIN-GAGE CAN AND THE HORTON SNOW-BOARD MEASUREMENTS OF SNOWFALL AT GRAND FORKS, N. DAK.

551.578.4 : 551.508.7

By ALBERT W. COOK

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There are many difficulties in the way of securing accurate measurements of snowfall. In addition to those inherent in the conditions attending precipitation in general, additional difficulties are introduced when the temperature is near or below the freezing point of water. When the wind is high or occurs in gusts, the snow is blown about and drifted so that the amount caught in the gage can is usually deficient. Under these conditions other means of measurement must be used. An open exposed spot is chosen and a number of measurements of the actual depth of the snow is taken and the average of these is assumed to be the true depth of the snow. This method of measuring gives a fairly close measurement of the depth if the ground was clear when the snow fell. When new snow has fallen on old snow, it is difficult to determine the depth of the new snow. This is especially true when snow is falling at the time of observation. Measurement must be made of the amount up to the time of observation and then the balance is to be measured at the next following observation. The line of division is one of time and not of snowfall and there is no definite mark between the amounts recorded at each observation.

To secure a means of eliminating this difficulty a snow board patterned after the one used by R. E. Horton [1] was used.

A piece of "compo" board about 2 feet square was covered with white cotton flannel with the rough or nap side uppermost. This was done to simulate a snow surface. After each snow the board was cleaned and placed on the newly fallen snow.

The actual depth of the snow could be secured by measuring the depth of the snow on the board. There would be no possibility of including the old snow.

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[1] MO. WEATHER REV., 1920; 48: 88–89.

The board also afforded a means of getting the ratio of snow to melted snow or the water equivalent, and a comparison of ground measurements of snowfall with the rain-gage overflow can measurements.

The amount of snow in the can was found by weighing the can and snow and subtracting the weight of the can. The depth of the snow on the board was measured and then a "cut" was taken by means of the 8-inch receiver top and the amount of the snow found by weighing as before. The ratio of the amount by weight to the depth on the board would give the water equivalent. To get the weight of 0.01 inch of water over the surface of the can, the diameter of which was 8 inches, the area of the surface was found and then by multiplying by 0.01 the volume would be given. The volume in cubic centi-

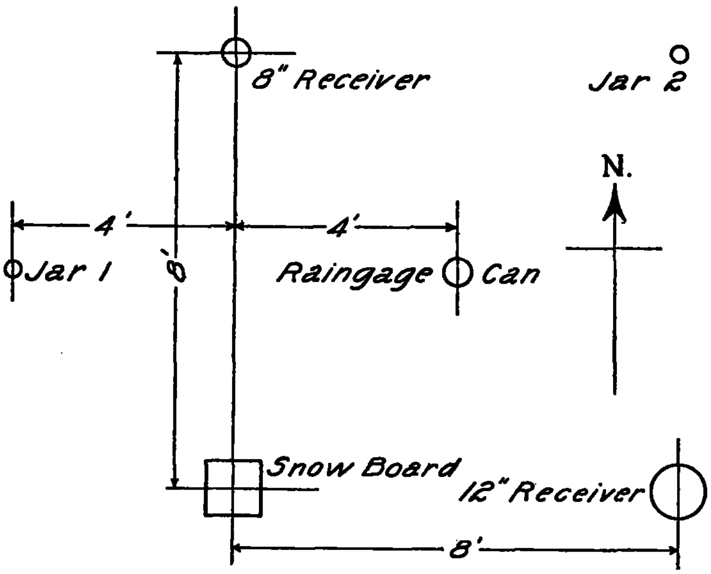

FIG. 1.—Arrangement of jars and receivers about the rain-gage can in test for influence of height of gage on catch of snow.

meters would give an equivalent number of grams since the density of water is unity. This was found to be 8.23 grams for each 0.01 inch of depth of water.

A wide variation in the ratio of snow to melted snow was found in the snows throughout the winter. In the heavy snow of February 19, it was 7.5 to 1 and on March 3, 42 inches of the light snow were required to make 1 inch of water. The water equivalent of the different snows are given in Table 1.

TABLE 1.—*Ratio of snow to melted snow*

Date	Depth of "cut"	Melted	Ratio	Wind	
				Direction	Velocity (miles per hour)
	Inches	*Inch*			
Jan. 11	1.5	0.05	30	N	4
Jan. 13	.12	.01	12	NW	6
Jan. 23	.4	.05	8	NW	7
Jan. 24, a. m.	3.5	.37	10	NW	15
Jan. 24, p. m.	.3	.03	10	N	17
Feb. 18	.5	.03	16⅔	SE	12
Feb. 19, a. m.	2.0	.12	16⅔	SE	12
Feb. 19, p. m.	.75	.10	7.5	NE	12
Mar. 5	2.25	.11	20	N	25
Mar. 8	1.13	.03	42	N	6

The snows of the winter were very light as shown by Table 1. The average ratio of all of the snows measured was 14 to 1, somewhat higher than the generally accepted value of 10 to 1.

In the first snow the rain-gage can measurement was about 50 per cent of the snow board measurement. It was thought that this might be due to the difference in height of the two. The greater amount on the snow board being due to drifting.

To determine the influence of height two battery jars 8 inches high, the 8-inch receiver top about 10 inches high, the 12-inch receiver top about 10 inches high, were arranged about the rain-gage can as shown by the diagram.

Table 2 shows the amount caught in each. The amount by weighing and the amount by melting and measuring as rain are both given. The slight variation in the two values may be credited to evaporation during melting.

TABLE 2.—*Comparison of snowfall measurements at Grand Forks*

[T indicates less than 0.01 inch]

Date	Gage can		8-inch "cut"		12-inch "cut"		8-inch receiver	
	Weight	Stick	Weight	Stick	Weight	Stick	Weight	Stick
Jan. 19, a. m.	T	T	0.01	0.01	0.01	T		
Jan. 23, p. m.	0.02	0.02	.05	.05	.05	0.05		
Jan. 24, a. m.	.19	.18	.37	.36	.37	.37	0.34	0.33
Jan. 24, p. m.	.03	.03	.03	.03	.026	.03	.03	.03
Jan. 27, p. m.	T	T	.01	.01	.01	.01	.01	T
Feb. 18, p. m.	.01	.01	.02	.01	.03	.01	.01	.01
Feb. 19, a. m.	.05	.04	.14	.13	.11	.10	.035	.02
Feb. 19, p. m.	.04	.04	.10	.10	.11	.10	.056	.06
Mar. 5, p. m.	.11	.10	.11	.10	.11	.11	.11	.10
Total	.45	.42	.84	.80	.83	.78		

Date	12-inch receiver		Jar I		Jar II	
	Weight	Stick	Weight	Stick	Weight	Stick
Jan. 19, a. m.						
Jan. 23, p. m.						
Jan. 24, a. m.	0.34	0.34	0.44	0.42	0.38	0.36
Jan. 24, p. m.	.029	.03	.029		.03	
Jan. 27, p. m.	.01	T		T		T
Feb. 18, p. m.						
Feb. 19, a. m.			.14		.15	
Feb. 19, p. m.			.08		.10	
Mar. 5, p. m.						

Mean of totals by standard rain-gage overflow can, 0.435 inch, melted.
Mean of totals by Horton snow board, 0.81 inch, melted.
Ratio of snow board to gage can, 1.86.

The variation between all except the can was slight and might be credited to wind gusts and drifting. All of the measurements are nearly double those of the can. From this it would appear that some other factor besides the height of the measuring devices causes the deficiency in the can.

The snow season this year was short and only a few real heavy snows occurred. However, measurements were taken on most of them throughout the winter. The can measurements are consistently below those of the snow board and the other devices used to catch the snow. In no case did the amount in the can exceed the amount caught on the snow board and in only two cases did it equal it.

In the light snows the measurements by both methods were very close, but in the heavier snows the snow-board measurement was about twice that of the gage can.

Measurements were taken during various wind velocities. Although these velocities bear no direct relation to the snow ratio, there seems to be some relation between them and the amounts caught on the snow board and in the gage can. In the two cases when the amoun tin the can equalled the amount caught on the board the wind velocities were the highest. In one case the velocity was 17 miles per hour and in the other case it was 25 miles per hour. In all other cases it was not over 15 miles per hour.

The temperature was well below freezing during the precipitation of all the snows listed in Table 2.

Referring to Table 2 we find that the total amount recorded by the rain-gage can was 0.435 inches and that of the snow board to be 0.81 inches, or 1.86 times that recorded by the gage can. In a seasonal snowfall of 32 inches, which is the average for Grand Forks for a period of 31 years, the deficiency would be 27.5 inches or taking it over the 31 year period, the total deficiency would be 738.6 inches, if rain-gage can measurements have been strictly adhered to in the past measurements.

TWILIGHT PHENOMENA ON MONT BLANC

E. BAUER, A. DANJON and JEAN LANGEVIN

(Comptes Rendus, 178, no. 25, June 16. 1924, pp. 2115–17)

[Translated by B. M. Varney, Weather Bureau]

We have studied the twilight phenomena at the Vallot Observatory on Mont Blanc (4,347 meters) under excellent, perhaps even exceptional, atmospheric conditions. Observations first undertaken in August, 1922, have been carried out from the 9th to the 14th of August, 1923. The interesting thing about a study at this altitude is the extreme simplicity and the almost astronomic regularity of the phenomena. Certain phases described in the standard works [1] were, however, missing. It is likely that the complications observed at a low altitude are in large measure the result of conditions in the dusty lower layers of the atmosphere, which extend upward to 3,000 to 3,500 meters.

1. *Phenomena opposite the sun. The earth's shadow.*—At 180° from the sun, one sees the shadow of the earth on the atmosphere; this is the ascent of night (la montée de la nuit), a blue-black segment bordered with purple in its upper part.

TABLE 1.—*Altitude of the blue segment (a. m.)*

$h_\odot$ = true solar altitude	0°	−2°	−4°	−5°	−6°
Altitude of the segment	−2°	+2°	+7°30′	+15°	+26°

NOTE.—The dip of the horizon at Vallot observatory is −2°.

The boundary of the segment is lost before it reaches the zenith and when the solar altitude h. = −7°.

The intersection of the solar ray which is tangent to the earth with the straight line from the observer to the summit of the segment, describes an elliptical arc leaving the earth at a distance of 100 kilometers [from the observer] and reaching the zenith at an altitude of about 45 kilometers.

2. *Phenomena observed on the side toward the sun. We have seen no evidence of the first twilight arch (9° from the sun), nor of the purple lights.*—Photographic records confirm these negative conclusions. The only one of the phenomena observed with great regularity is the second twilight arch: at the horizon a reddish segment, above that a yellow segment, and finally a much larger segment of a greenish blue very pure in tone, its upper boundary rather sharply drawn, and above it the night. This varicolored segment appears to us to constitute a wholly unique thing, differing widely from that which one infers from the standard descriptions, which are mostly confused and contradictory.

It appears to be useless to make a distinction between the reflected light of twilight (the Dämmerungsschein of Pernter-Exner) [2] and the twilight arch properly so called.

TABLE 2.—*Altitudes of the twilight arch (p. m.)*

$h_\odot$	8°	10°	12°	14°	17°50′
Red/yellow boundary	−1°10′	−1°	−0°55′	−0°45′	----------
Yellow/blue boundary	+0°40′	+0°30′	+0°10′	0°	----------
Blue/night boundary	+10°	+7°30′	+4°35′	+2°20′	−2°

The boundary of the twilight arch (blue/night) passes the zenith at a solar altitude of −4° 40′. It is thus a phenomenon independent of the ascent of night, the edge of which attains the zenith only when the solar altitude is −7° or −8°. The arch disappears completely at h. = −17° 50′.

It seems to us impossible to explain the twilight arch on the basis of a reflection of the purple light as Pernter and Exner have done.[3] It appears more likely that it is due to diffusion of direct sunlight by the atmosphere included between the shadow cone of the earth and a certain limiting altitude z. But if we compute z, we obtain numbers which increase as the sun declines.

TABLE 3.—*Altitude of the twilight arch (p. m.)*

$-h_\odot$	4°35′	10°	14°	16°	17°
z (km.)	14	30	39	42	44

It is to be observed that the measurements of the twilight arch and of the ascent of night give the same altitude for the highest diffusion layers, about 45 kilometers.

We have observed 30 minutes after the setting of the twilight arch, a new luminous segment, very faint, fairly well defined but irregular, which disappeared little by little below the horizon.

This segment, which does not seem to be due to the zodiacal light, is perhaps a third twilight arch. Its summit is at about 9° altitude when $h_\odot = -21°$. The diffusion layer which would cause it would therefore reach 180 kilometers altitude and would be identical with the absorptive layer observed by us in 1922.[4]

3. *Photometric mesaurement of the brightness of the zenithal sky.*—The measurements were carried out according to the photometric method of Fabry,[5] slightly

[1] Pernter and Exner, Meteorologische Optik, 2d ed., 1922, p. 845 et seq.
[2] loc. cit., p. 856.

[3] loc. cit., p. 898.
[4] Comptes Rendus, 176, 1923, p. 761.
[5] The Director of the Bureau of Standards, Washington, D. C., has kindly contributed the following comment on the nature of the Fabry photometric method.

"While the reference to method of measurement is somewhat indefinite, we judge that it refers to a type of photometer described by H. Buisson and Charles Fabry in the Journal de Physique, page 25, 1920. A brief description of this instrument is also given in abstracts printed in the Transactions of the Illuminating Engineering Society, volume 16, page 92, 1921. This instrument is designed particularly for the measurement of very faint sources, and apparently it can be used for the direct comparison of the light from a small source with that for a luminous area. For example, it would make possible the direct comparison of the light from a star with that of a given area of the sky, and it would then be possible to express the brightness of a given region in terms of the intensity of a single star such as Vega. This would involve simply an estimate or a determination of the solid angle included in the field of view of the photometer, and evidently the authors have expressed this solid angle in a unit which they call a 'degree square.'"